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CANCER INCIDENCE AMONG MEDICAL DIAGNOSTIC X-RAY WORKERS IN CHINA, 1950 TO 1985[1]

Ji-Xian Wang[2], Peter D. Inskip[3,4], John D. Boice, Jr.[3], Ben-Xiao Li[2], Jing-Yuan Zhang[2] and Joseph F. Fraumeni, Jr.[3]

[2]*Institute of Radiation Medicine, Chinese Academy of Medical Sciences, Tianjin, China; and* [3]*Epidemiology and Biostatistics Program, Division of Cancer Etiology, National Cancer Institute, National Institutes of Health, Bethesda, MD 20892, USA.*

A second follow-up of 27,011 diagnostic X-ray workers in China revealed a 21% greater incidence of cancer than expected based on the experience of 25,782 physicians who did not routinely use X-rays (RR = 1.21; 95% Cl: 1.08 to 1.35). This risk is lower than the 50% excess reported previously and reflects, in part, the reduced risk among workers first employed after 1965, when hospital exposures to radiation probably were lower than in earlier years. The X-ray workers were employed between 1950 and 1985 and followed for an average of 16.1 years. Significantly elevated risks were seen for leukemia (RR = 2.4, n = 34 cases), and cancers of the esophagus (RR = 5.2, n = 19), liver (RR = 1.8, n = 65), and skin (RR = 2.8, n = 9). Cancers of the breast (RR = 1.5, n = 20), thyroid (RR = 1.7, n = 8), and bone (RR = 7.6, n = 4) also occurred more often than expected. Non-significant deficits were observed for cancers of the oral cavity and pharynx (RR = 0.6, n = 16), colon and rectum (RR= 0.8, n = 20), stomach (RR = 0.8, n = 36), and lung (RR = 0.9, n = 45). Excess risks for leukemia and esophageal cancer were seen among men but not among women. The RR for leukemia was higher for X-ray workers who began employment before 1970 than for those who started more recently and also for those who were young when employment began. The patterns of risk associated with duration of work, and with age and calendar time of initial employment, suggest that the excesses of leukemia and skin cancer, and, possibly, cancers of the breast and thyroid, were due to occupational exposure to X-rays. However, there was little evidence that radiation contributed to the increased occurrences of liver or esophageal cancers.

Most estimates of the carcinogenic hazards of ionizing radiation are based on the experience of persons who received large doses of radiation within a short time period. These include studies of survivors of the atomic bomb explosions in Japan and people irradiated for a variety of medical reasons (Boice and Land, 1982). The applicability of these data in assessing cancer risks to persons who experience prolonged or repeated exposure to low-level ionizing radiation, such as occurs in certain occupations, is uncertain (UNSCEAR, 1988).

Studies of male radiologists in the United States (Lewis, 1963; Matanoski *et al.*, 1975 and 1984) and United Kingdom (Smith and Doll, 1981) documented excess mortality due to leukemia and skin cancer among those who began work during the first part of this century. The risks decreased in more recent years, presumably because of reductions in radiation exposure attributable to safer methods and machines. The surveys of radiologists showed no consistent excess of other cancers. In addition, cancer mortality among men who served as radiologic technicians in the US Army during World War II was similar, overall and by cancer site, to that of a group of medical, laboratory, or pharmacy technologists (Jablon and Miller, 1978). Information on cancer incidence rather than mortality and for women as well as men was added by a study of more than 27,000 medical X-ray workers in China (Wang *et al.*, 1988). In that work, we reported a 50% overall excess of cancer among X-ray workers relative to a comparison group of other Chinese physicians, a strong association between radiation work and leukemia (RR = 3.5, n = 30 cases) and small excesses of cancers of the breast, thyroid, and skin among persons employed for 10 or more years. Although the study population was large, the average period of observation was only 11 years. Here, we report on an additional 5 years of follow-up.

METHODS

Characteristics of the study population and methods of cancer ascertainment and data analysis were described in detail in the earlier report (Wang *et al.*, 1988). The cancer experience of 27,011 diagnostic X-ray workers, including radiologists and technicians, was compared and contrasted with the experience of 25,782 surgeons, otolaryngologists, and other physicians who worked at the same hospitals during the same time period (1950–1985) but did not use X-rays in their work. The study population was drawn from major hospitals situated in 24 provinces. Approximately equal numbers of X-ray workers and comparison subjects were enrolled from each hospital. Twenty percent of the X-ray workers and 31 % of the comparison group were female. Average ages at first employment were 26 years for the X-ray workers and 25 years for the comparison group. The earliest calendar year of first employment was 1926, but more than 98% of the X-ray workers started work after 1949.

The previous analysis evaluated cancer incidence for 1950 through 1980. The current analysis extended the evaluation through December 31, 1985 and also included updates to the 1950–80 follow-up. Cancers were ascertained by reviewing administrative records at the hospital where each individual worked. If a cancer was noted, medical records were examined to identify exact diagnosis and the date and basis of the diagnosis. Cancers were coded according to the 8th Revision of the International Classification of Diseases (ICD-8) (WHO, 1969).

The period of observation for each person began with the date of first employment or January 1, 1950, whichever came later, and ended with the date of cancer diagnosis, date of death, or December 31, 1985, whichever came first. Approximately 435,000 PY (person-years) of observation were accrued by the exposed group (average = 16.1), and 523,000 PY by the comparison group (average = 20.3).

Expected (E) numbers of cancers among the X-ray workers were estimated based on incidence rates of the comparison group. Standardized incidence rate ratios (RR) were calculated using the age by sex by calendar time PY distribution among the exposed as weights. Ninety-five percent confidence intervals (CI) for the RR were calculated according to a method that accounts for random variation in expected numbers (Rothman and Boice, 1982; Breslow, 1984).

Cancer incidence rates among radiation workers and comparison subjects also were compared with 1973 to 1975 rates from the Shanghai Cancer Registry (Waterhouse *et al.*, 1982).

[1]This work is an analysis of data collected by the National Coordinating Research Group of Dose-Effect Relationships in Medical Diagnostic X-ray Workers in China.

[4]To whom reprint requests should be sent, at the National Cancer Institute, Executive Plaza North, Suite 408, Bethesda, MD 20892, USA.

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TABLE I - OBSERVED NUMBERS OF INCIDENT CANCERS AMONG DIAGNOSTIC X-RAY WORKERS, EXPECTED NUMBERS BASED ON COMPARISON GROUP, AND STANDARDIZED RATE RATIOS (RR) FOR SPECIFIC SITES, BY DURATION OF EMPLOYMENT. NUMBERS OF PERSON-YEARS OF OBSERVATION FOR THE X-RAY WORKERS (PY_e) AND COMPARISON SUBJECTS (PY_0) ALSO ARE SHOWN

Site (ICD-8)	Cancer occurrence	Duration of employment (years)					
		<5	5–9	10–14	15–19	>20	Total
	PY_e:	136,713	115,760	73,038	46,409	62,620	434,540
	PY_0:	124,932	117,496	96,717	77,350	106,051	522,546
All (140–209)	Observed	19	47	74	64	128	332
	Expected	28.5	42.4	45.3	46.8	111.2	274.2
	RR	0.7	1.1	1.6	1.4	1.2	1.2[1]
Oral cavity and pharynx (140–147)	Observed	0	3	2	1	10	16
	Expected	3.26	4.34	4.70	4.59	8.18	25.1
	RR	0.0	0.7	0.4	0.2	1.2	0.6
Esophagus (150)	Observed	3	1	3	3	9	19
	Expected	0.20	0.30	0.33	0.51	2.30	3.64[2]
	RR	14.9	3.3	9.1	5.8	3.9	5.2[1]
Stomach (151)	Observed	0	3	13	3	17	36
	Expected	4.98	8.04	7.35	7.11	18.0	45.4
	RR	0.0	0.4	1.8	0.4	0.9	0.8
Colon (153)	Observed	0	0	2	3	1	6
	Expected	1.22	1.70	1.63	1.35	3.10	9.00
	RR	0.0	0.0	1.2	2.2	0.3	0.7
Rectum (154)	Observed	2	1	3	0	8	14
	Expected	2.33	2.94	2.52	2.95	6.43	17.2
	RR	0.9	0.3	1.2	0.0	1.2	0.8
Liver (155)	Observed	4	13	9	14	25	65
	Expected	3.61	4.86	5.53	7.25	14.7	36.0
	RR	1.1	2.7	1.6	1.9	1.7	1.8[1]
Pancreas (157)	Observed	1	0	2	2	3	8
	Expected	0.25	0.49	0.74	1.15	5.53	8.16
	RR	4.1	0.0	2.7	1.7	0.5	1.0
Lung (162)	Observed	3	4	4	12	22	45
	Expected	2.83	5.54	7.21	7.98	26.3	49.9
	RR	1.1	0.7	0.6	1.5	0.8	0.9
Bone (170)	Observed	1	1	1	0	1	4
	Expected	0.12	0.23	0.16	0.02	0.00	0.52
	RR	8.4	4.4	6.4	0.0	>100.0	7.6
Skin (173)	Observed	0	1	0	3	5	9
	Expected	0.19	0.39	0.61	0.64	1.43	3.26
	RR	0.0	2.5	0.0	4.7	3.5	2.8[1]
Breast (174)	Observed	0	3	4	4	9	20
	Expected	2.08	2.48	2.62	3.00	3.07	13.2
	RR	0.0	1.2	1.5	1.3	2.9	1.5
Bladder (188)	Observed	0	1	1	1	3	6
	Expected	0.52	1.72	1.27	0.31	1.83	5.65
	RR	0.0	0.6	0.8	3.3	1.6	1.1
Cervix uteri (180)	Observed	0	1	1	1	0	3
	Expected	0.30	0.49	0.60	0.55	1.56	3.50
	RR	0.0	2.1	1.7	1.8	0.0	0.9
Ovary (183)	Observed	0	0	1	1	2	4
	Expected	0.29	0.62	0.62	0.51	1.29	3.33
	RR	0.0	0.0	1.6	2.0	1.6	1.2
Brain/CNS (191)	Observed	0	0	2	3	2	7
	Expected	0.81	1.61	1.71	1.30	2.73	8.16
	RR	0.0	0.0	1.2	2.3	0.7	0.9
Thyroid (193)	Observed	0	2	3	3	0	8
	Expected	0.60	0.69	0.88	1.00	1.63	4.80
	RR	0.0	2.9	3.4	3.0	0.0	1.7
Lymphosarcoma (200)	Observed	0	2	2	0	0	4
	Expected	1.11	1.05	1.29	0.97	0.74	5.16
	RR	0.0	1.9	1.6	0.0	0.0	0.8
Multiple myeloma (203)	Observed	0	0	0	0	0	0
	Expected	0.10	0.26	0.31	0.31	0.29	1.27
	RR	0.0	0.0	0.0	0.0	0.0	0.0
Lymphatic leukemia (204)	Observed	0	2	4	2	0	8
	Expected	0.13	0.18	0.24	0.36	0.96	1.86
	RR	0.0	11.1	16.7	5.6	0.0	4.3[1]

(continued)

TABLE I - OBSERVED NUMBERS OF INCIDENT CANCERS AMONG DIAGNOSTIC X-RAY WORKERS, EXPECTED NUMBERS BASED ON COMPARISON GROUP, AND STANDARDIZED RATE RATIOS (RR) FOR SPECIFIC SITES BY DURATION OF EMPLOYMENT, NUMBERS OF PERSON-YEARS OF OBSERVATION FOR THE X-RAY WORKERS (PY_e) AND COMPARISON SUBJECTS (PY_0) ALSO ARE SHOWN *(continued)*

Site (ICD-8)	Cancer occurrence	Duration of employment (years)					
		<5	5–9	10–14	15–19	>20	Total
Myeloid leukemia (205)	Observed	1	5	7	4	1	18
	Expected	0.61	0.86	1.00	1.15	2.64	6.26
	RR	1.6	5.8	7.0	3.5	0.4	2.9[1]
All leukemia (204–207)	Observed	2	7	15	6	4	34
	Expected	1.30	1.77	2.34	2.90	5.76	14.1
	RR	1.5	4.0	6.4	2.1	0.7	2.4[1]

[1]One-sided $p < 0.05$. Only the overall (marginal) RR for each type of cancer was tested.–[2]Reclassification of a case coded as esophageal cancer in the previous analysis (Wang *et al.*, 1988) lowered the incidence rate for the comparison group and, therefore, the expected number of cases among the exposed.

RESULTS

Cancer incidence among the diagnostic X-ray workers was 21% greater than expected based on incidence in the comparison group (RR = 1.21; 95% CI: 1.08 to 1.35), and most of the excess occurred among workers who had been employed for 10 or more years (Table I). Actual numbers of excess cancers were greatest for cancers of the liver (RR = 1.8; 95% CI: 1.2 to 2.6) and esophagus (RR = 5.2; 95% CI: 1.9 to 12.7), and for leukemia (RR = 2.4; 95% CI: 1.3 to 4.1). Incidence also was elevated for cancers of the bone (RR = 7.6; 95% CI: 0.6 to 60), skin (RR = 2.8; 95% CI: 0.9 to 9.4), breast (RR = 1.5; 95% CI: 0.8 to 2.7), and thyroid (RR = 1.7; 95% CI: 0.6 to 4.7). Six of the 9 skin cancers were on the hands. There were deficits of 20% for stomach and colorectal cancers, 40% for cancer of the oral cavity and pharynx, and 10% for lung cancer. Cancer of the pancreas occurred approximately at the expected frequency. No cases of multiple myeloma were observed, but only one was expected. Lymphatic and myeloid leukemias occurred more often than expected among the X-ray workers, but monocytic leukemia did not (RR = 0.8; O = 3). Only 1 of the lymphatic leukemias was chronic lymphatic leukemia (CLL); the other 7 were acute. The myeloid leukemias were split equally between chronic and acute subtypes.

Variation in the RR by duration of employment differed among cancer types (Table 1). The relative excess of leukemia was highest among workers who had been employed between 10 and 15 years, but no excess was apparent among those employed more than 20 years. On the other hand, the RR for breast cancer increased with increasing duration of employment, and most of the skin cancer excess occurred among people who had worked with X-rays for at least 15 years. The RR for liver and esophageal cancers were elevated for all length-of-employment categories.

Incidence of all cancers combined was greater than expected among male X-ray workers but not among females (Table II). All cases of esophageal cancer occurred among men, and the excesses of leukemia and skin cancer were also confined to male workers, The RR for several relatively common cancers (stomach, colon-rectum, and lung) were close to 1.0 for males, but 50 to 60% deficits were recorded among females.

An overall excess of cancer was observed only among X-ray workers first employed before 1970 (Table III), and the RR for leukemia was higher for these early years. The RR for breast and thyroid cancers were highest among people who began work before 1960, but the differences between calendar year groups were unstable. The RR for cancers of the esophagus and liver were elevated in all 3 categories, though the excess of liver cancer was small among recently hired workers. There was a deficit of stomach cancers among those who began work in 1970 or later. Because workers starting after 1969 have been observed, on average, for only one-third as long as those starting before 1960, they would have less time to accumulate dose and to accommodate latency intervals for cancer appearance.

A cross-classification of observed and expected numbers of leukemia by year of first employment and time since employment began is shown in Table IV. X-ray workers who started before 1960 experienced about an 8-fold RR of leukemia 10 to 20 years after their initial exposure, but they showed no excess after 20 years. For workers who began employment in the 1970s, the RR between years 5 and 15 was lower than for the other groups.

The RR for leukemia and thyroid cancer decreased with increasing age at first employment (Table V). The RR for all cancers combined, exclusive of leukemia, was highest among workers first employed before age 20, but data otherwise suggest a uniform RR across age-at-employment categories, Average observation times ranged from 19.9 years among people younger than 20 when they started work down to 11.7 years among those aged 40 or over. The highest RR for breast cancer was seen among women who were aged 25 to 29 at the start of employment.

An excess of breast cancer was apparent only among women who had attained the age of 45 years. The RR was 1.0 for age at observation of less than 45 (n = 10) and 3.3 for women older than 45 (n = 10).

An overall excess of cancer was observed only between 1950 and 1980 (Table VI). During the extended follow-up, 1981 to 1985, a 10% deficit of cancer was seen among the X-ray workers. Decreases in the RR were most prominent for leukemia and cancers of the esophagus and thyroid. Risks also declined for cancers of the stomach, colon-rectum and liver, but increased for cancers of the breast, skin and bone. The deficit of cancer from 1981 to 1985 occurred mainly among workers whose employment began after 1964 (Table VII). A slight, non-significant excess was observed among persons who started working earlier.

DISCUSSION

Although the radiation doses received by these medical X-ray workers are unknown, it is likely that average doses were higher in the earlier years than more recently. It was common, for example, for workers to be given time off when their white blood cell counts fell below a certain level. The first national radiation protection guidelines in China were issued in the late 1950s, but marked improvements in radiation safety and reductions in average exposures probably did not occur until the mid-to-late 1960s.

With 5 additional years of follow-up beyond our earlier survey (Wang *et al.*, 1988), 106 additional cancers were detected among the X-ray workers. The RR for all cancers combined,

TABLE II - OBSERVED (O) NUMBERS OF CANCERS OF SELECTED SITES AND STANDARDIZED RATE RATIOS (RR), SEPARATELY FOR MALE AND FEMALE DIAGNOSTIC X-RAY WORKERS

	Males		Females	
Person-years:	343,494		91,046	
Average age at entry (yr):	26.4		26.7	
Average year at entry:	1970		1969	
Cancer site	O	RR	O	RR
All sites	271	1.3	61	0.8
Esophagus	19	8.4	0	0.0
Stomach	32	0.9	4	0.4
Colon and rectum	18	0.9	2	0.4
Liver	61	1.8	4	1.4
Lung	40	1.0	5	0.5
Bone	3	[1]	1	1.9
Skin	8	4.4	1	0.7
Breast	0	0.0	20	1.5
Thyroid	3	1.6	5	1.7
Leukemia	29	3.0	5	1.1

[1]O/E ratio (RR) could not be calculated because no cases occurred among the comparison subjects in the relevant age-sex-calendar year strata.

however, dropped from 1.4 to 1.2, and the RR for leukemia fell from 3.2 to 2.4. The leukemia results fit well with those for radiologists in the US (Matanoski *et al.*, 1975) and UK (Smith and Doll, 1981) and are readily interpretable in terms of a declining secular trend in radiation exposure among X-ray workers and a wave-like pattern of excess leukemia risk following radiation exposure (Land, 1987). Each increment of dose can be thought of as adding an increment of risk (Thomas, 1983). Incremental risks attributable to the larger doses of the early years now appear to have subsided, and risks due to lower doses in recent years presumably are smaller in relation to background hazards. Assuming an excess relative risk coefficient of 1 to 3% per cGy, based on data for populations with acute exposures (Boice *et al.*, 1987; Preston *et al.*, 1987), the average dose for this population is estimated to have been 45 to 140 cGy. If fractionation of dose lowers the risk of radiogenic leukemia (and animal data suggest that it does) (Major and Mole, 1978), the actual doses might have been considerably higher.

Time-response and dose-reponse relationships for this population are intertwined. Workers accumulated dose with increasing duration of employment. The RR for leukemia following a single, large radiation exposure or several large, closely-spaced fractional exposures typically reaches a peak within the first 5 or 10 years following exposure and then declines (Boice *et al.*, 1987; Preston *et al.*, 1987; Darby *et al.*, 1987). The RR for these X-ray workers was highest 10 to 15 years after employment began. Several years of employment might have been required to accumulate a sufficient dose to produce a large increase in risk.

Cancers of the breast, thyroid and lung, along with leukemia, are believed to be the tumors most readily caused by radiation (BEIR, 1980). In the present study, small excesses were observed for cancers of the breast and thyroid, but incidence of lung cancer was slightly below the expected rate. The RR for breast cancer was highest among women who had been employed as X-ray workers for 20 years or more. The literature suggests that fractionation of dose does not appreciably lessen the risk of radiogenic breast cancer (Land *et al.*, 1980). Assuming art excess relative risk coefficient of 0.7% per rad (Hrubec *et al.*, 1989), an average dose can be estimated crudely as approximately 70 cGy. The RR for lung cancer did not increase with increasing duration of employment, which argues against a radiation effect being obscured by negative confounding, such as that due to less frequent smoking among X-ray workers in relation to the comparison group. The low RR might be explained by the relative youth of the study population (average age at close of follow-up = 43 years), if radiogenic lung cancer appears only at older ages. Only 3% of the total PY of observation were for ages 55 or older. Alternatively, fractionation of dose might lower the risk of radiogenic lung cancer, as suggested by studies of tuberculosis patients who received large numbers of chest fluoroscopies (Davis *et al.*, 1989). We note, however, that a small excess of lung cancer was observed among pioneering British (Smith and Doll, 1981), but not American (Matanoski *et al.*, 1975), radiologists.

The leukemia excess was seen among male X-ray workers but not among females. Prior studies (Boice *et al.*, 1987; Preston *et al.*, 1987) do not suggest that men are greatly, if at all, more susceptible than women to radiation leukemogenesis. One can speculate that male and female X-ray workers typically performed somewhat different duties and that men received higher doses. However, it would be inconsistent to invoke such a hypothesis while simultaneously attributing the excesses of breast and thyroid cancer among women to radiation exposure, unless the female breast and thyroid are particularly susceptible to radiation carcinogenesis following fractionated exposures. Alternatively, cancer ascertainment might have been more complete among the male X-ray workers than among the females.

Death due to skin cancer occurred more often than expected among British radiologists first employed before 1921 (Smith and Doll, 1981) and US radiologists registered in a professional society before 1940 (Matanoski *et al.*, 1975). Skin cancer also occurred more often than expected in our cohort of X-ray workers from China, with most of the tumors arising on the hands. The hands would have been exposed to X-rays if, for example, they were used to position or steady a patient during an X-ray procedure. Most of the excess cases occurred among people employed as X-ray workers for at least 15 years, and it is likely that radiation exposure contributed to the increased risk.

Lung cancer was not the only cancer for which our results differed from other surveys of radiologists. Unlike Lewis (1963) and Matanoski *et al.* (1975), we did not observe an excess of multiple myeloma among X-ray workers, nor did we observe an excess of pancreatic cancer, as was seen by Smith and Doll (1981) for radiologists who started work early this century. Incidence of multiple myeloma is lower in China than in the United States (Miller, 1978). Only one case was expected among the X-ray workers in this study, and a RR as high as 3 is consistent with the data, based on the 95% CI. Bone cancer risk was elevated among the Chinese X-ray workers, but not in the other studies of radiologists. The large relative risk (RR = 7.6), however, was based on only 3 to 4 excess bone cancers, and the distribution of the excess by calendar year of first employment was not suggestive of a radiation effect. Bone cancer induction by X-rays has been reported only following high doses (BEIR, 1980; Tucker *et al.*, 1987).

Large excesses in risk were observed for cancers of the esophagus and liver, neither of which is considered to be readily induced by radiation, except for hepatic angiosarcomas and cholangiocarcinomas caused by Thorotrast (BEIR, 1980). We have no data about liver cancer cell type or the use of Thorotrast in China. Espohageal and liver cancers (hepatic cell carcinoma) are very common in certain areas of China. The excess of esophageal cancer occurred only among men, while the RR for liver cancer was similar for the 2 sexes. Neither site showed a trend toward increasing RR with increasing duration of employment. These observations suggest that the X-ray workers and the comparison group differed with respect to risk factors for these cancers apart from radiation, such as history of hepatitis B infection, alcohol consumption, or diet.

TABLE III - OBSERVED (O) NUMBERS OF INCIDENT CANCERS AMONG DIAGNOSTIC X-RAY WORKERS AND STANDARDIZED RATE RATIOS (RR) FOR SELECTED SITES, BY CALENDAR YEAR OF FIRST EMPLOYMENT

	Calendar year of first employment					
	<1950–1989		1960–1969		1970–1985	
Average years of observation:	30.4		21.5		10.2	
Cancer site	O	RR	O	RR	O	RR
All sites	193	1.3	90	1.3	49	0.8
Esophagus	13	5.5	4	5.3	2	3.8
Stomach	26	1.1	7	0.7	3	0.2
Liver	37	1.8	20	2.2	8	1.2
Lung	23	0.7	16	1.6	6	0.7
Bone	2	7.1	0	0.0	2	[1]
Skin	7	2.9	1	1.6	1	4.8
Breast	10	1.7	6	1.3	4	1.3
Thyroid	5	2.4	2	1.2	1	1.0
Leukemia	17	2.6	13	3.0	4	1.3

[1]O/E ratio could not be calculated because no bone cancers occurred among the comparison group in the relevant age-sex-calendar year strata.

TABLE IV - CASES OF LEUKEMIA OBSERVED (O) AND EXPECTED (E) AMONG X-RAY WORKERS, AND STANDARDIZED RATE RATIO (RR), BY CALENDAR YEAR OF STARTING WORK AND TIME SINCE EMPLOYMENT BEGAN

Year of starting work		Years since started work						All years
		0–4	5–9	10–14	15–19	20–29	>=30	
Before 1960	O	0	1	9	4	3	0	17
	E	0.00	0.07	0.38	1.23	3.60	1.36	6.64
	RR	0.0	14.3	23.7	3.3	0.8	0.0	2.6
1960–1969	O	1	4	5	1	2	0	13
	E	0.05	0.34	1.19	1.61	1.14	0.00	4.33
	RR	20.0	11.8	4.2	0.6	1.8	0.0	3.0
1970–1985	O	1	2	1	0	—	—	4
	E	1.14	1.26	0.70	0.03	—	—	3.13
	RR	0.9	1.6	1.4	0.0	—	—	1.3
All years	O	2	7	15	5	5	0	34
	E	1.20	1.67	2.27	2.86	4.74	1.34	14.1
	RR	1.7	4.2	6.6	1.8	1.1	0.0	2.4

TABLE V - OBSERVED (O) NUMBERS OF INCIDENT CANCERS AMONG DIAGNOSTIC X-RAY WORKERS AND STANDARDIZED RATE RATIOS (RR), BY AGE AT FIRST EMPLOYMENT

Age at first employment	All cancers except leukemia		Leukemia		Breast cancer		Thyroid cancer	
	O	RR	O	RR	O	RR	O	RR
<20	24	1.5	5	5.9	0	0.0	2	5.4
20–24	70	1.1	15	4.1	6	1.4	3	2.0
25–29	91	1.3	8	2.2	10	3.3	2	1.6
30–34	60	1.3	5	1.9	4	1.6	1	1.2
35–39	28	0.9	1	0.6	0	0.0	0	0.0
>=40	25	0.8	0	0.0	0	0.0	0	0.0
All ages	298	1.1	34	2.4	20	1.5	8	1.7

Extended follow-up lowered the RR not only for leukemia but also for all solid cancers combined. There are several possible explanations for this finding. Results for 1981–85 are influenced more by the experience of recently hired workers who, presumably, received lower radiation doses and who were followed for relatively short intervals. However, the RR for all solid cancers among workers first employed before 1965 was lower for 1981–85 than for earlier years, and even the updated follow-up for the 1950–80 period yielded slightly lower RRs for most cancers in comparison to results reported in our earlier study. This suggests that cancer ascertainment might initially have been more complete for X-ray workers than for the comparison group, but that more recent and exhaustive follow-up has corrected this disparity.

RR based on comparisons with 1973 to 1975 cancer incidence rates for the population of Shanghai were 0.54 for the radiation workers (O/E = 332/612) and 0.48 for comparison subjects (O/E = 386/803). Deficits among both groups are to be expected, because cancer mortality rates for Shanghai are among the highest in China (Li, 1982). It is noteworthy, however, that the RR for the comparison group is nearly equal to the value reported previously (0.46), based on 1950 to 1980 follow-up (Wang *et al.*, 1988), while the RR for radiation workers has decreased from the earlier value of 0.66. This suggests that the difference between the RR for cancer reported here (1.21) based on an internal comparison of radiation and non-radiation workers, and the RR given in the earlier paper (1.50) (Wang *et al.*, 1988) is not due solely to initially poor follow-up for the comparison group, but instead reflects a decrease in cancer risk among radiation workers in recent years.

Repeated exposure to sparsely ionizing, low-dose radiation appears to have caused leukemia, skin cancer and, perhaps,

TABLE VI - OBSERVED NUMBERS OF CASES (O) AND STANDARDIZED RATE RATIOS (RR) FOR CANCERS **OF** SELECTED SITES, BY CALENDAR YEAR OF OBSERVATION

Site	Calendar year of observation					
	1950–1980[1]		1981–1985		1950–1985	
	O	RR	O	RR	O	RR
All sites	226	1.4	106	0.9	332	1.2
Esophagus	15	7.6	4	2.4	19	5.2
Stomach	29	1.1	7	0.4	36	0.8
Colon-rectum	15	1.0	5	0.4	20	0.8
Liver	48	2.1	17	1.2	65	1.8
Pancreas	3	0.7	5	1.4	8	1.0
Lung	22	0.8	23	1.0	45	0.9
Bone	3	5.7	1	[2]	4	7.6
Skin	6	1.8	3	[2]	9	2.8
Breast	10	1.2	10	2.1	20	1.5
Thyroid	8	2.1	0	0.0	8	1.7
Leukemia	30	3.2	4	0.8	34	2.4

[1]Numbers differ slightly from those given in Wang *et al.* (1988) because of subsequent updates and corrections.–[2]O/E ratio could not be calculated because no bone or skin cancers occurred among the comparison group in the relevant age-sex-calendar year strata.

TABLE VII - OBSERVED (O) AND EXPECTED (E) NUMBERS OF CANCER OTHER THAN LEUKEMIA, BY YEAR IN WHICH X-RAY WORK BEGAN AND CALENDAR YEAR OF OBSERVATION

Year of starting work		Calendar year of observation			
		1950–1964	1965–1980	1981–1985	1950–1985
Before 1965	O	18	146	68	232
	E	9.0	110.1	64.3	183.4
	RR	2.0	1.3	1.1	1.3
1965–1985	O	—	32	34	66
	E	—	30.0	46.8	76.8
	RR	—	1.1	0.7	0.9
All years	O	18	178	102	298
	E	9.0	140.1	111.1	260.2
	RR	2.0	1.3	0.9	1.1

cancers of the breast and thyroid among Chinese X-ray workers. As with radiologists in the US (Matanoski et *et al.,* 1975) and UK (Smith and Doll, 1981), risk of radiogenic cancer appears to have declined over time, although not until recently in China. Although dose per X-ray exposure would have been small, cumulative doses might have been considerable. An average dose of 100 cGy for this population is consistent with the available data, with higher doses during earlier years and lower doses more recently. Important limitations of this study include the lack of individual dosimetry (a problem shared with many retrospective studies of medical radiation workers), the small number of PY of observation for older ages, probable differences between X-ray workers and the comparison group with respect to unmeasured cancer risk factors, and possible differences in the completeness of cancer ascertainment. Information is also lacking on cell types of cancers other than leukemia, and efforts will be made to obtain this information, especially for cancers of the liver, bone and skin. Although radiogenic risks can be inferred for leukemia and certain other cancer sites, a substantial part of the overall cancer excess among the Chinese X-ray workers appears to be due to factors other than radiation.

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